

Attorney Docket No. 76315

HIGH-STRENGTH PARTS FORMED USING STEREOLITHOGRAPHY

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT ROBERT V. KIERONSKI, citizen of the United States of America, employee of the United States Government and resident of Newport, County of Newport, State of Rhode Island has invented certain new and useful improvements entitled as set forth above of which the following is a specification:

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5 STATEMENT OF GOVERNMENT INTEREST

6 The invention described herein may be manufactured and used
7 by or for the Government of the United States of America for
8 Governmental purposes without the payment of any royalties
9 thereon or therefor.

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11 BACKGROUND OF THE INVENTION

12 (1) Field of the Invention

13 The present invention relates generally to manufactured
14 parts, and more particularly to high-strength parts having
15 exterior surfaces that are precision manufactured using a
16 stereolithographic method/apparatus while having an interior core
17 made from a high-strength material.

18 (2) Description of the Prior Art

19 Complex models can now be quickly and accurately made by
20 linking computer-aided design (CAD) model specifications with a
21 commercially available process known as stereolithography. A
22 stereolithography apparatus (or SLA as it is known) takes CAD
23 data and automatically produces a hard plastic pattern or model
24 in a matter of hours. The patterns or models are three
25 dimensional and include any design features that are made
26 available by most general-use CAD systems. Examples of such SLA
27 systems include those disclosed in U.S. Patent Nos. 4,575,330

1 (Hull), 5,104,592 (Hull et al.), 5,216,616 (Masters), and
2 5,263,130 (Pomerantz et al.)

3 The basic concept of stereolithography is as follows. A
4 part design is created on a CAD system and then downloaded to the
5 control unit of an SLA. The control unit directs a movable laser
6 beam onto the surface of a tank filled with a liquid polymer that
7 is photo-curable. An elevator table resides just below the
8 surface of the liquid polymer. In operation, the polymer
9 solidifies to a thickness of approximately 0.005-0.030 inches
10 wherever the laser beam strikes the surface of the liquid photo-
11 curable polymer. To construct a cross-section of the part, the
12 laser beam is scanned back and forth on the surface in the shape
13 of the cross-section. The elevator table is then lowered a
14 programmed amount so that the just-solidified cross-section is
15 covered with the liquid polymer. Another cross-section of the
16 part is then created on top of the first cross-section in the
17 same manner as described above. The process continues until the
18 complete part has been constructed. Finally, the part is removed
19 from the tank and cured.

20 While producing complex parts accurately and quickly using
21 stereolithography has many advantages, the cured polymer part
22 does not typically provide the strength characteristics required
23 of the actual part. Thus, functional testing of the SLA created
24 part is not usually possible and must therefore be delayed until
25 the part can be cast or machined from an appropriate strength
26 material.

27

1 SUMMARY OF THE INVENTION

2 Accordingly, it is an object of the present invention to
3 utilize the speed and accuracy of stereolithography in forming
4 high-strength parts.

5 Another object of the present invention is to provide a
6 method of making a precision manufactured part having the
7 strength characteristics necessary for the functional testing of
8 the part.

9 Other objects and advantages of the present invention will
10 become more obvious hereinafter in the specification and
11 drawings.

12 In accordance with the present invention, high-strength
13 parts are produced by first performing a stereolithography part
14 generation process to create a polymer part having opposing
15 interior surfaces. An uncured strength material is interposed
16 between the opposing interior surfaces of the polymer part. The
17 polymer part with the uncured strength material is then heated.
18 The strength material is chosen to bond to the opposing interior
19 surfaces during the heating step. The strength material
20 comprises either a mixture of an epichlorohydrin resin, a
21 catalyst and filler particles, or a mesh wetted with a catalyzed
22 epichlorohydrin resin.

1 BRIEF DESCRIPTION OF THE DRAWING(S)

2 Other objects, features and advantages of the present
3 invention will become apparent upon reference to the following
4 description of the preferred embodiments and to the drawings,
5 wherein:

6 FIG. 1A is a cross-section of an arbitrarily-shaped,
7 stereolithography-generated polymer part for use in an embodiment
8 of the present invention;

9 FIG. 1B is a cross-section of the part of FIG. 1A partially
10 filled with a secondary material in accordance with the present
11 invention;

12 FIG. 1C is a cross-section of the high-strength part
13 produced in accordance with the present invention;

14 FIG. 2A is a cross-section of arbitrarily-shaped,
15 stereolithography-generated polymer shells that can nest with one
16 another in accordance with another embodiment of the present
17 invention;

18 FIG. 2B is a cross-section of the polymer shells of FIG. 2A
19 and a reinforcing mesh saturated with a catalyzed resin
20 interposed between the shells; and

21 FIG. 2C is a cross-section of the polymer shells after they
22 have been pressed together in nested engagement about the
23 catalyzed resin-wetted reinforcing mesh used to form the high-
24 strength part.

25

1 DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

2 Referring now to the drawings, and more particularly to
3 FIGS. 1A, 1B and 1C, one embodiment of the present invention will
4 be described. In FIG. 1A, a cross-section of an arbitrarily-
5 shaped hollow polymer part is referenced generally by numeral 10.

6 Part 10 is designed/constructed using a stereolithography
7 apparatus (SLA) to achieve the desired exterior dimensions. A
8 variety of such SLA systems are known in the art and will,
9 therefore, not be described further. Typically, polymer part 10
10 is made from an epoxy resin polymer developed and sold by Ciba
11 Geigy Corporation under the tradename CIBATOOL™ SL5180 or
12 SL5170. However, the present invention is also compatible with
13 other epoxy polymer systems.

14 In terms of the present invention, polymer part 10 is
15 designed/constructed to have inner shell 12 with interior surface
16 12a and outer shell 14 with interior surface 14a. Interior
17 surface 12a and interior surface 14a oppose one another and are
18 separated from one another by gap 16 that is fairly uniform
19 throughout polymer part 10 in accordance with the precision of
20 the particular SLA system. Gap 16 is maintained by a plurality
21 of spaced-apart internal supports 18 formed integrally with inner
22 shell 12 and outer shell 14 of the same polymer material during
23 the stereolithography construction process. Spacing between
24 supports 18 is selected to provide sufficient flow area for
25 passage of a viscous secondary material (as will be described
26 further below), while sufficiently maintaining the integrity of
27 gap 16. The design of polymer part 10 can be accomplished with

1 the aid of any one of a variety of patterning software packages
2 used in conjunction with an SLA. For example, one such
3 patterning software package is available under the tradename
4 QUICKCAST™ from Ciba Geigy Corporation. Briefly, the structure
5 of polymer part 10, i.e., inner shell 12, outer shell 14 and
6 supports 18, is photo-cured during a stereolithography process
7 and any uncured liquid polymer is drained via, for example, holes
8 20, 21 and 22, thereby leaving gap 16.

9 With polymer part 10 constructed as in FIG. 1A, a secondary
10 material is introduced as will be described with the aid of FIG.
11 1B. Like reference numerals will be used for the elements common
12 with FIG. 1A. In this embodiment of the present invention,
13 secondary material 30 is injected between inner shell 12 and
14 outer shell 14 using holes 20 and 21, for example, as indicated
15 by arrows 40. Hole 22 in this example allows the displaced air
16 in gap 16 to escape as indicated by arrow 42. Accordingly,
17 secondary material 30 is in a liquid state when it fills gap 16.

18 To assure uniform filling of secondary material 30 between inner
19 shell 12 and outer shell 14, the injection indicated by arrow 40
20 can be pressure assisted using pump 41 while the venting of air
21 indicated by arrow 42 can be vacuum assisted using vacuum 43.
22 The completely filled part, referenced generally by numeral 50 in
23 FIG. 1C, is then heated so that secondary material 30 bonds to
24 polymer part 10 as secondary material 30 cures. Thus, part 50
25 has a precision contoured exterior provided by the
26 stereolithographic process while having a core with the strength
27 properties of the cured secondary material 30.

1 In its uncured liquid form, secondary material 30 should be
2 easily castable. Upon curing, secondary material 30 must bond
3 with the photo-cured polymer material used in the
4 stereolithographic part generation process. Once cured,
5 secondary material 30 must have a coefficient of expansion
6 similar to that of the photo-cured polymer material.

7 In general, when polymer part 10 is formed from an epoxy
8 resin polymer as described above, secondary material 30 is a
9 catalyzed epoxy resin that is mixed with filler particles for
10 added strength. The epoxy resin for secondary material 30 should
11 be one having its basic epoxidizing resin based on
12 epichlorohydrin. The catalyst is chosen based upon the desired
13 pot life. That is, if the part to be constructed were
14 geometrically complex, a longer pot life may be desired to allow
15 for complete filling of the stereolithographic part. For
16 example, one catalyst which does not add to the basic viscosity
17 of the epichlorohydrin resin is methylenedimethylene (THPA). A
18 pot life of about two hours is achieved when methylenedimethylene
19 is added to an epichlorohydrin resin at 80-90 weight percent of
20 the epichlorohydrin resin's weight. For most applications, a two
21 hour pot life is adequate. Other suitable catalysts include
22 hexahydrophthalic anhydride (HHPA), dodecenylsuccinic anhydride
23 (DDSA), and polyamide.

24 Immediately after mixing the resin and catalyst, strength-
25 enhancing filler particles are added and mixed thoroughly with
26 the mixture of resin and catalyst. The mixture of resin,
27 catalyst and filler particles forms secondary material 30 for

1 injection between inner shell 12 and outer shell 14. Choice of
2 the particular material for the filler particles varies with the
3 thickness of gap 16 and the desired strength properties of the
4 filled polymer part. For example, for gaps up to approximately
5 $3/4$ of an inch in thickness, milled glass fiber in the range of
6 $1/32$ to $1/64$ of an inch in length can be added to the mixture of
7 resin and catalyst in a proportion that is 50-60 weight percent
8 of the resin's weight. (While strength increases with the
9 increase in filler material, the mixture can become too viscous
10 is if the stated proportion is exceeded.) In addition, if gap 16
11 is between approximately $1/4$ to $3/4$ of an inch, aluminum powder
12 is added in a proportion up to 10 weight percent of the resin's
13 weight. The aluminum powder aids in heat dispersion during the
14 curing process.

15 After secondary material 30 (e.g., either the mixture of
16 resin, catalyst and filler or the mixture of resin, catalyst,
17 filler and metal powder) fills the SLA generated part, the filled
18 part is cured. Curing is accomplished by heating the filled part
19 to a fairly low temperature of approximately 125°F until
20 secondary material 30 cures to a useful strength, i.e., a
21 strength greater than the strength of the photo-cured polymer
22 material.

23 The present invention can also be implemented by
24 constructing the stereolithographic part as two arbitrarily-
25 shaped nesting shell as will now be described with the aid of
26 FIGS. 2A, 2B and 2C. In FIG. 2A, a cross-section is shown of

1 polymer part 100 formed of first shell 112 and second shell 114.
2 Surface 114a of shell 114 is contoured and shaped to nest with
3 surface 112a of shell 112. Surfaces 112b and 114b form the
4 exterior surfaces of part 100. As shown in FIG. 2B, a mat or
5 mesh 120 is interposed between shells 112 and 114. As will
6 become apparent below, mesh 120 serves as fiber reinforcement and
7 is typically constructed from glass or graphite fiber bundled
8 cables or tows. The mesh size and thickness are dependent on the
9 required properties of the end part. Generally, the more mesh
10 material, the greater the strength of the object incorporating
11 same. Usually, the placement and orientation of the fibers are
12 chosen such that the greatest number of uninterrupted fibers are
13 placed along the axis where the greatest tensile strength is
14 required.

15 Mesh 120 is wetted with a catalyzed resin such as the
16 epichlorohydrin resin mixed with the methylenedimethylene catalyst
17 as described in detail above. For purpose of illustrations, the
18 catalyzed resin is depicted in FIG. 2B as dashed lines 122 both
19 above and below mesh 120 in order to indicate that mesh 120 is
20 saturated with the catalyzed resin.

21 When shells 112 and 114 are pressed into nested engagement
22 with one another as shown in FIG. 2C, mesh 120 saturated with
23 catalyzed resin 122 conforms to the nested arrangement of shells
24 112 and 114. Further, mesh 120 separates opposing surfaces 112a
25 and 114a to essentially define a uniform separation between
26 shells 112 and 114 similar to the uniform gap maintained by
27 supports 18 in the embodiment of FIGS. 1A, 1B and 1C. Any excess

1 catalyzed resin is squeezed out of the ends of shells 112 and 114
2 as indicated by arrows 124. Additional vents (not shown) can
3 also be provided in each of shells 112 and 114 for venting
4 purposes. As with the first embodiment, a vacuum (not shown) may
5 be applied to the various vents to assist in the removal of
6 excess catalyzed liquid and/or air bubbles. The nested part with
7 reinforcing mesh 120 saturated with catalyzed resin 122 is then
8 cured at a fairly low temperature, e.g., 125EF, as described
9 above.

10 The advantages of the present invention are numerous. The
11 accuracy and efficiency of stereolithography are combined with a
12 strength material in a novel fashion to produce a high-strength
13 part. In this way, a stereolithographic part can be tested for
14 both form and function.

15 It will be understood that many additional changes in the
16 details, materials, steps and arrangement of parts, which have
17 been herein described and illustrated in order to explain the
18 nature of the invention, may be made by those skilled in the art
19 within the principle and scope of the invention as expressed in
20 the appended claims.